The challenge of astrometric planet searches - How to select stable target and reference stars

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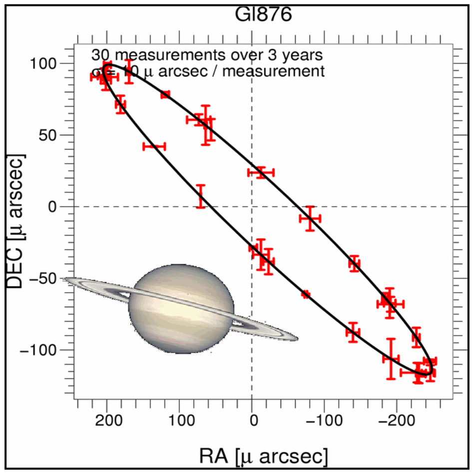


SUMMARY: **Precise astrometry** is a powerful tool to detect and **characterize extrasolar planets**, very complementary to radial velocity surveys.In particular, the radial velocity method is restricted to certain types of stars and leaves the inclination angle of the orbit (*sin* i) undetermined, thus providing only a lower limit to the mass of the planets. Astrometry has a different detection bias, favoring planets in large orbits versus the short-period orbits preferentially detected by the radial-velocity technique. Moreover, astrometry measures two components (right ascension and declination) of the stellar reflex motion versus the single radial component that is observable spectroscopically. To play a significant role, an astrometric accuracy of order **10µarcsec** is needed, which is beyond the performance of current instrumentation (including HST). However, differential astrometry relies on **phase reference stars**. Target and reference star pairs have to fulfil tight requirements on separation, brightness, distance, physical stellar parameters, and, in particular, on **astrometric stability**. In preparation of a ground-based astrometric planet search program with PRIMA at the ESO-VLTI, we systematically investigate the effect of various **astrophysical factors** that potentially affect the detection of an astrometric signal due to an orbiting planet and explore the detection domain for this method. Some of our results may also be applicable to other, e.g., space-based astrometric planet searches like the SIM program.

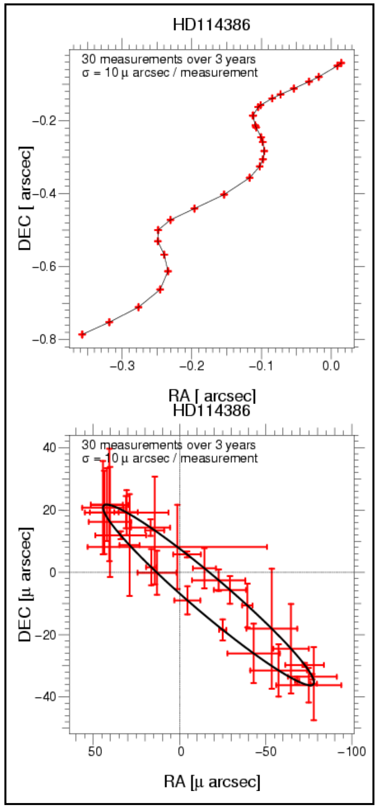
Searching planets with astrometry

- High-precision astrometry measures the 2-D projection of the spatial displacement of a star due to an orbiting planet. Radial-velocity searches measure a 1-D velocity component of that same reflex motion. Both methods have different, but overlapping detection spaces and different detection biases.

- Astrometric 2-D measurements of planetary orbits allow to solve for *sin*i (which the RV method leaves undetemined) and to derive the planet masses.

- To play a significant role and to be sensitive for Jupiter-like planets around more than the most nearby stars, an astrometric precision of 10µarcs or better has to be achieved. One instrument that aims to achieve this goal within the next 2-3 yr and that is currently being developed, is the PRIMA-DDL system at the ESO VLTI.

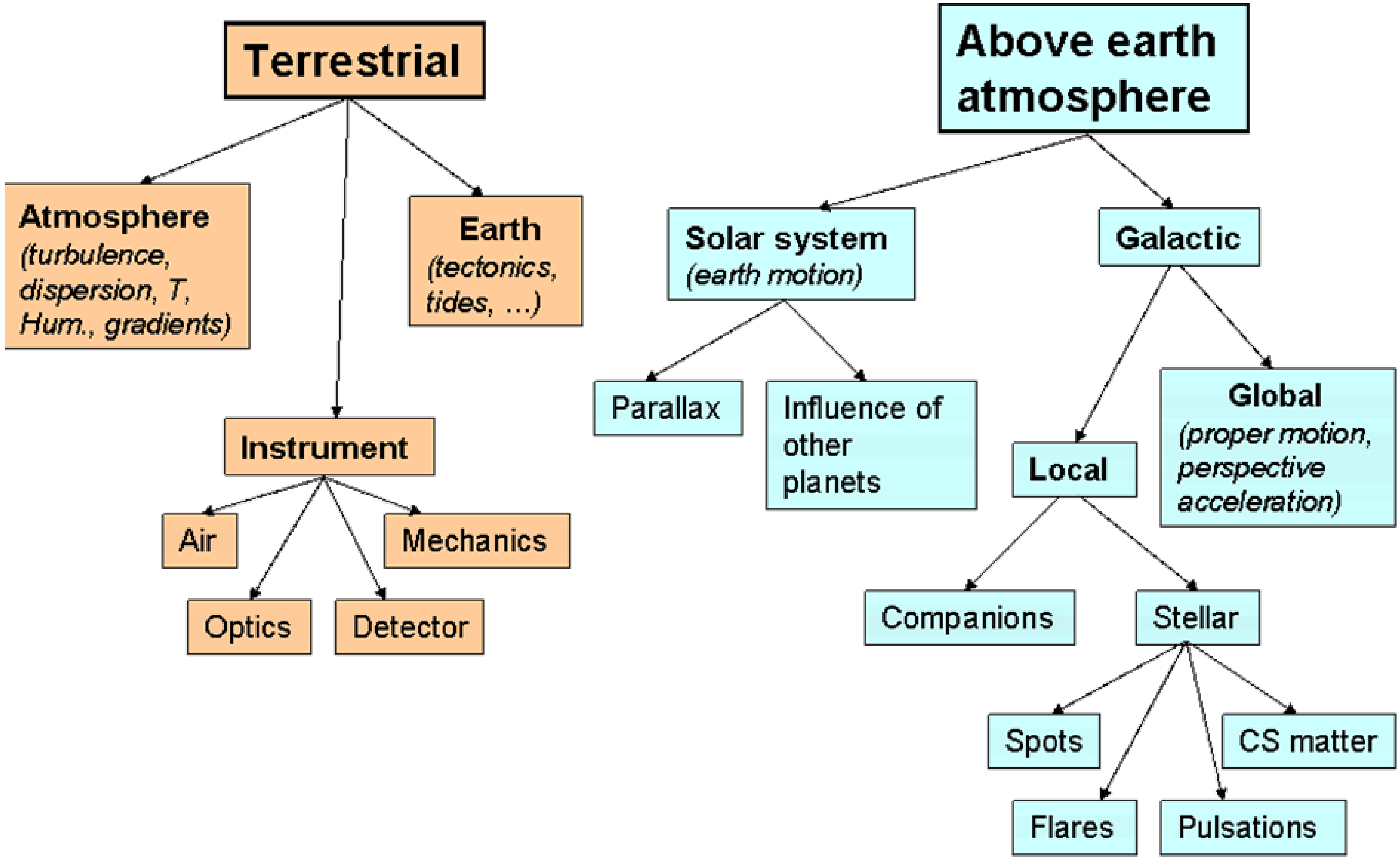
- While SIM attemps to define a fixed astrometric grid, ground-based astrometry can only provide differential measurements with respect to phase reference stars within the isoplanatic patch. Since such a reference system is not fixed, a planetary orbit can only be determined within a global solution for parallax and proper motion of both target and reference stars.



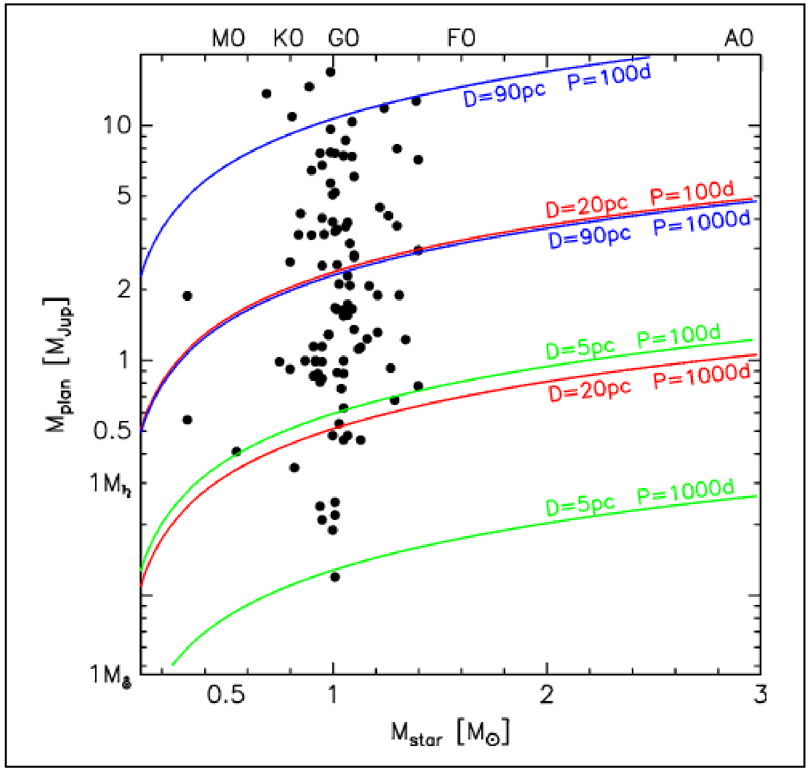
Example: $1M_{sun}$ MS star at D=10pc with $1M_{Jup}$ planet and P=3yr

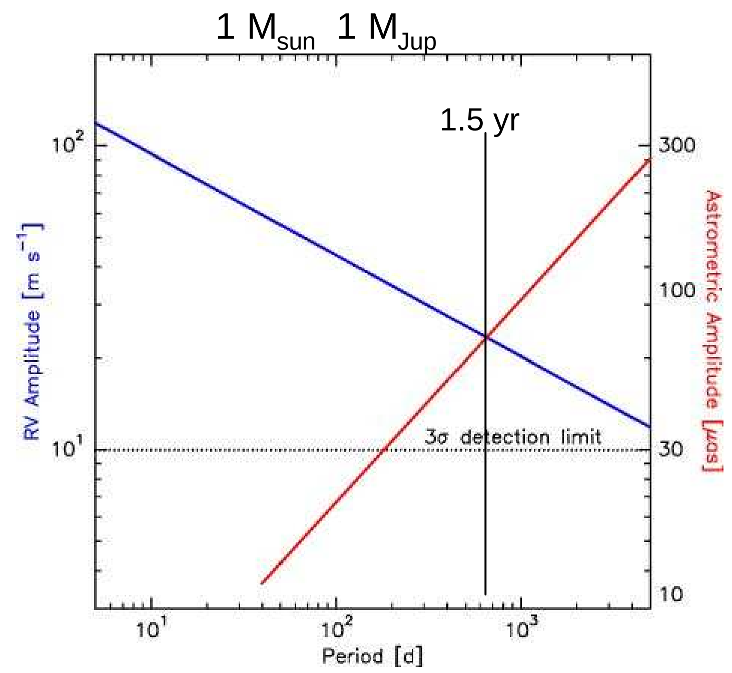
Parallax:	100marcs	*Proper motion:*	10-1000 marcs/yr
Planet reflex:	200µarcs	*Chromospheric Activity:*	1-5µarcs

Simplified astrometry error tree



Where can we find what kind of planets?





Astrometry: $\rho \approx M_{Pl}\, M_*^{-2/3}\, P^{2/3}\, D^{-1}$

RV: $K \approx M_{Pl}\, \sin i\, M_*^{-2/3}\, P^{-1/3}\, 2\pi G$

- Star and planet mass discovery parameter space as function of orbital period and distance for astrometric 5σ sensitivity of 50µarcs.
- Around nearby M stars, the method is sensitive down to Neptune mass planets in 3yr orbits, provided these stars form such planets, one finds astrometrically stable stars, and the orbit is well-sampled.
- Apart from certain stellar types that are not accessible to the RV method but to astrometry, 10µarcs astrometry tends to win over RV planet searches for periods > 1.5 yr (for star with 1 M_{sun} and planet with 1 M_{Jup})

Rotational modulation due to starspots

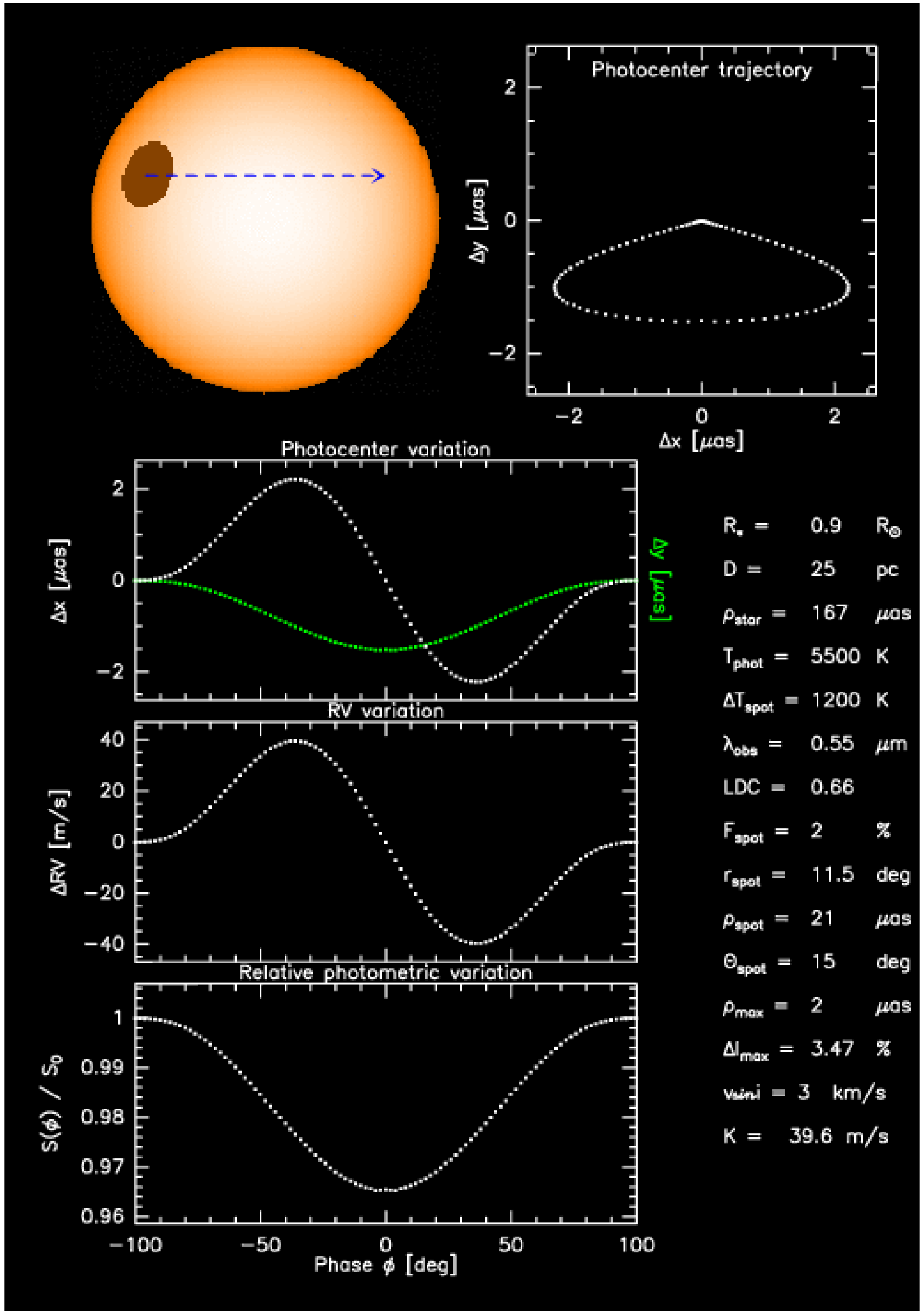
- Chromospheric inhomogenities (e.g., spots) on the rotating stellar surface produce astrometric, radial velocity, and photometric signals.

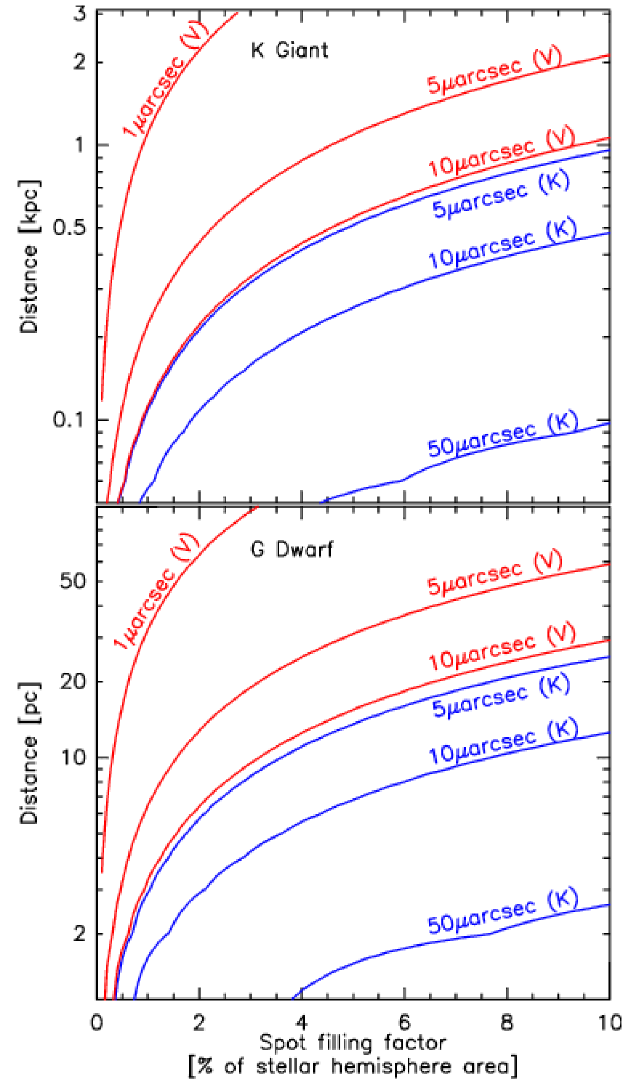
- We have modeled the effects for simple edge-on (sini=1) geometry and a single spot, using realistic stellar parameters, spot temperatures, and limb darkening coefficients.

- The effects are much smaller at K-band (PRIMA@VLTI) than V-band (SIM).

- The simulations show that for ground-based differential astrometry at K-band and 10μarcs accuracy, spots are of concern only for the most nearby target and reference stars (typically distant K giants).

- Starspots appear to be of serious concern for SIM, especially for astrometric grid stars.

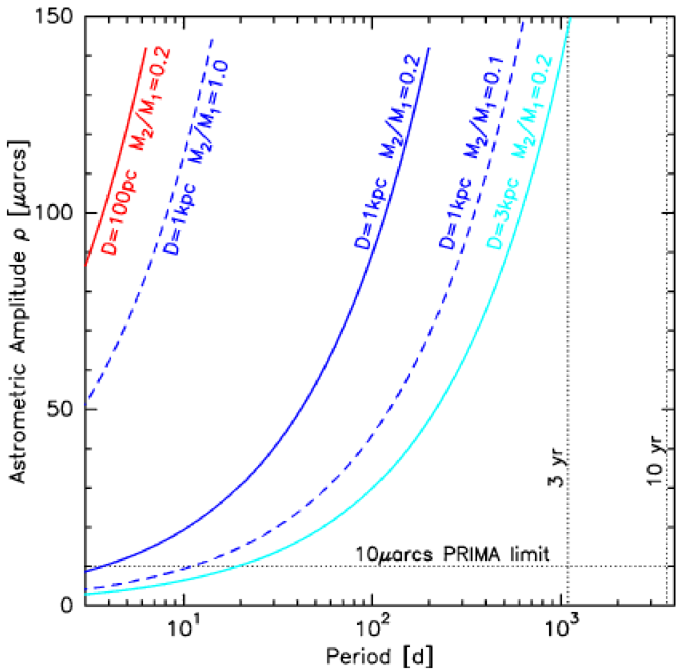




Astrometric signal at VIS (SIM) and K-band (PRIMA) due to star spots on a G dwarf target star and K giant reference star.

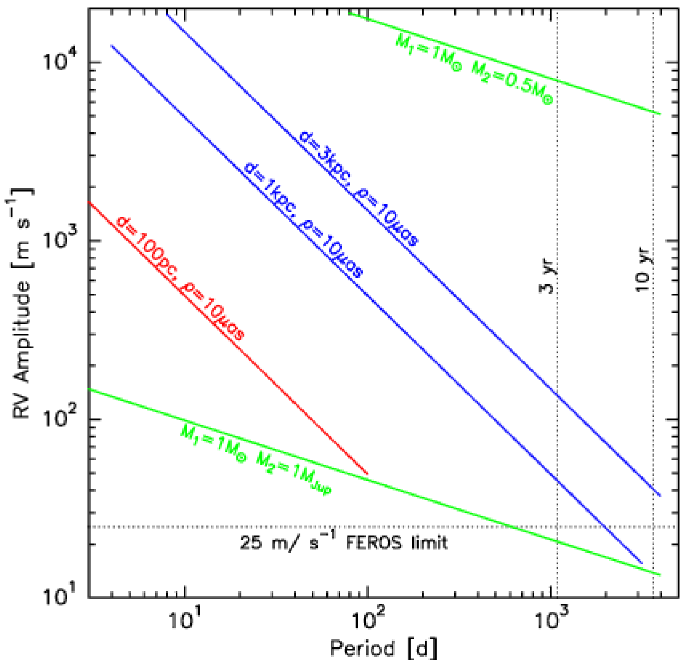
Unwanted companions

- Unknown stellar and substellar companions around both target and reference stars produce astrometric signals that could hinder the detection of a planet.
- Apart from extremely long-period binaries and certain binary target stars, all binaries that produce a detectable signal should be excluded.
- However, binarity is quite common (e.g., ≈40% among K field stars, average mass ratio ≈0.7). That means, a large fraction of potential target and reference stars will have stellar companions.
- Figure 1 → Even short-period companions around distant reference stars produce large astrometric signals.
- Figure 2 → Short and intermediate-period unwanted binaries can be identified with moderate effort through radial velocity measurements.
- Companions around reference stars with periods of several years are problematic. They can produce astrometric variations > 10µarcs, but their RV signal is close to the detection limit.



1. Astrometric amplitude due to a companion with mass ratio 0.2 as function of orbital period and for different distances (red: target star distance limit, blue: potential refernce stars). The effect of the mass ratio is shown for D=1kpc.

$$\rho^3 = M_2^3/M_1^3\ (M_1+M_2)\ GP^2/4\pi^2D^3$$

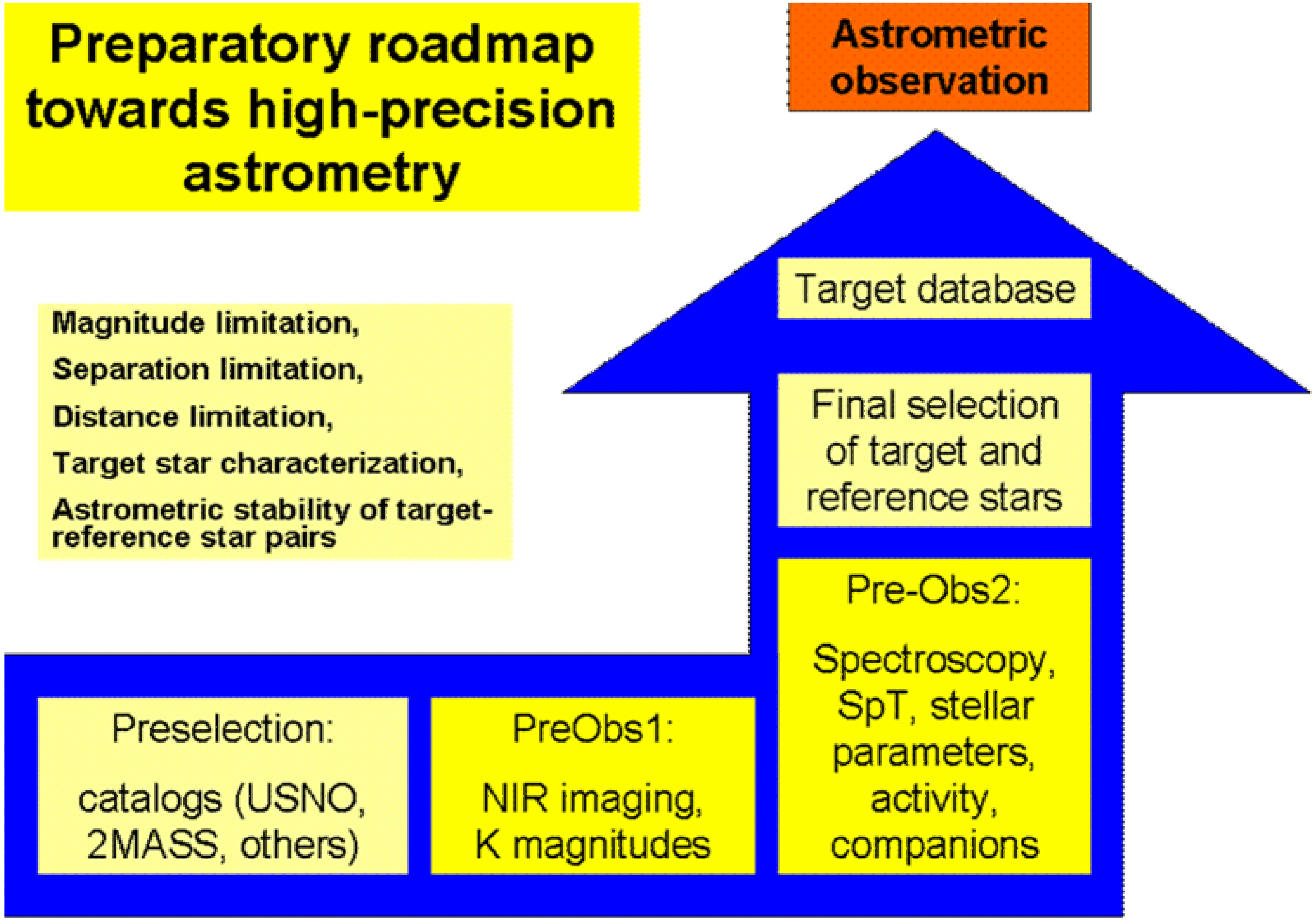


2. RV amplitude as function of period for certain primary and secondary masses (green lines, range from $1M_{Jup}$ around solar-mass star to mass ratio 0.5 binary). Red and blue lines: RV amplitude of systems that produce an astrometric signal of 10μarcs.

$$K^3 = M_2^3/(M_1+M_2)^3\ 2\pi G/P$$

$$\rho = K\ P/2\pi D\ (1+M_2/M_1)$$

$$(e\equiv 0 \quad \sin i \equiv 1)$$


Preparatory roadmap towards high-precision astrometry
Astrometric observation
Target database
Magnitude limitation,
Separation limitation,
Distance limitation,
Target star characterization,
Astrometric stability of target-reference star pairs
Final selection of target and reference stars
Pre-Obs2:
Spectroscopy, SpT, stellar parameters, activity, companions
Preselection:
catalogs (USNO, 2MASS, others)
PreObs1:
NIR imaging, K magnitudes